Methods for Agent-Based Computer Modelling

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Conférences & Séminaires

1.6. Methods for Agent-Based Computer Modelling

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The aim of this plenary session is to present the family of computer modelling methods grouped together under the term "agent-based modelling". Indeed, the use of these methods has been developed over the last twenty years in a growing number of academic disciplines and scientific fields of study, particularly in social sciences. They allow us to envisage reproducing and studying a part of the real world's complexity by carrying out veritable *in silico* experimentations, called "simulations", in which the individual and collective dynamics of computerised entities called "agents" are programmed, observed and analysed in as many details as necessary. These simulations can confirm the appearance of phenomena concerning the emergence of complex dynamics of a "whole" from the behaviours of "parts", suggest cause-effect relationships, allow us to test different scenarios of evolution, or to scientifically prove, by experiment, different hypotheses. They above all allow us to make concrete, in the form of easily manipulated abstractions, the multi-disciplinary exchanges about a same object within common models that can be verified thanks to their expressive power, in direct relationship with observations of the real world.

This general presentation will be followed by the presentation of the *Multi-Agent for Environmental Norms Impact Assessment* (MAELIA) project in which a simulation platform is developed of the effects of the implementation of norms for management and governance for water resources, territories and the environment. This platform has been chosen because it offers an excellent illustration of the couplings that allow us to realise agent-based models, between, for example:

- The geochemical and hydrological dynamics on the scale of a catchment area;
- The occupation and use of land and its incidence on resources;
- The human activities linked to the exploitation or management of resources;
- The effects of climate change, particularly on water resources.

The aim of the project is to evaluate the direct/indirect, expected/unexpected effects of the implementation of norms on a territory where renewable resources such as water, which depend on complex physical processes, are at the same time submitted to competitive uses by heterogeneous social players.

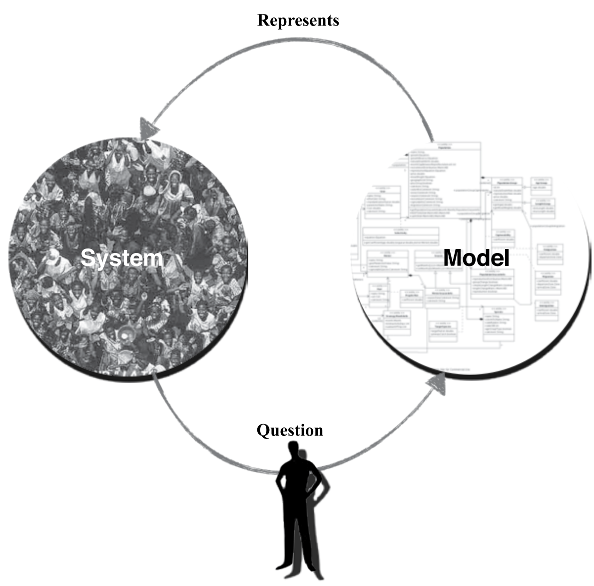
(Retranscription)

Alexis Drogoul

I shall begin this presentation with an introduction that will raise awareness of the field of analysis, and then Benoit Gaudou will illustrate the use of these techniques within the framework of an application of the MAELIA project concerning water management by a certain number of players involved. I hope to obtain a lot of feedback and questions in order to help make our presentation clearer, in full knowledge that many other points will be addressed next week during the workshop, where we will see how to build models using these techniques.

I shall begin with a few definitions that might seem extremely simple, but it is essential to clarify vocabulary that is often polysemic.

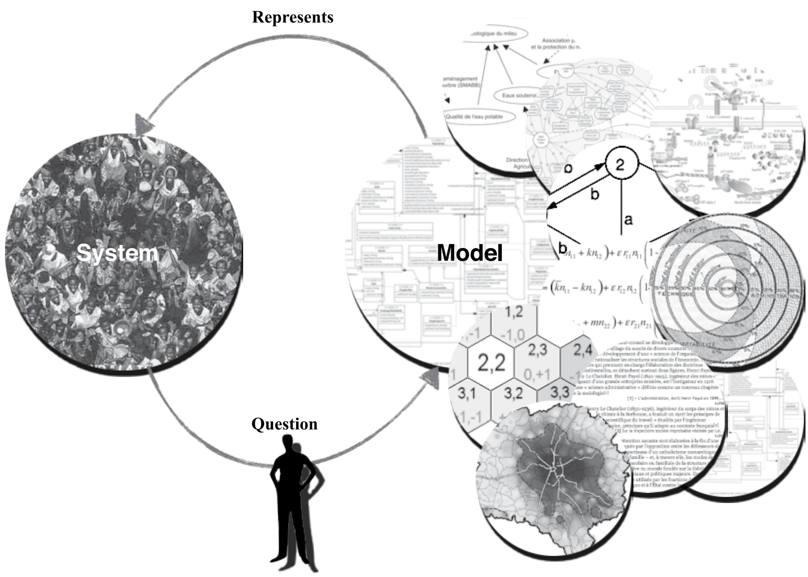
Diagram 6 Model



Sources: Authors' construction.

A model is a simplified and abstract representation of a demarcated system of reference that helps reply to a question, or support discussion and reflection in a more simplified framework. This representation can be communicated and shared.

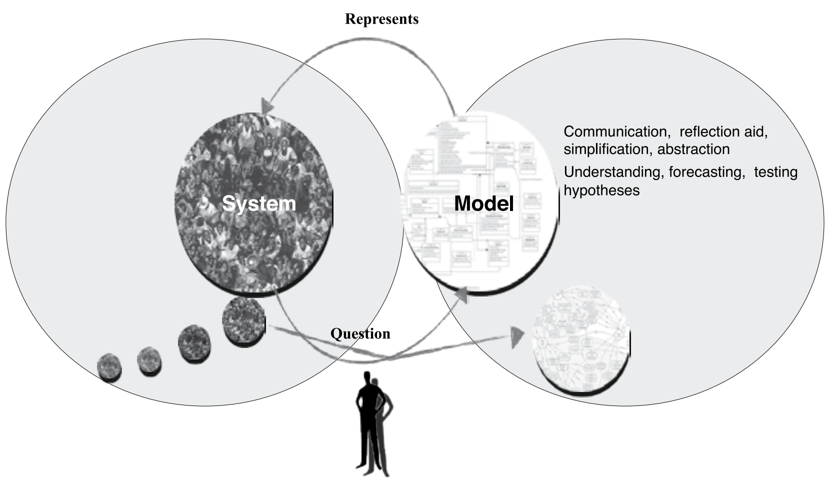
Diagram 7 Representation(s)



Sources: Authors' construction.

A model can be written by using any imaginable formalism. There exist purely literary and mathematical models, and between the two exist a whole range of models based upon production tools, interpretations and traditions. We have, for example, domains in social sciences which are based upon certain traditions and which use at the same time mathematical tools or statistics depending on the question and the inherent traditions of this discipline. If you are more interested in a spatial question, you are going to need systems of analysis such as geographical information systems (GIS); if you are interested in equilibrium mechanisms, you are going to use dynamic systems, that is to say a mathematical representation, etc.

Diagram 8 Static Models, Dynamic Models



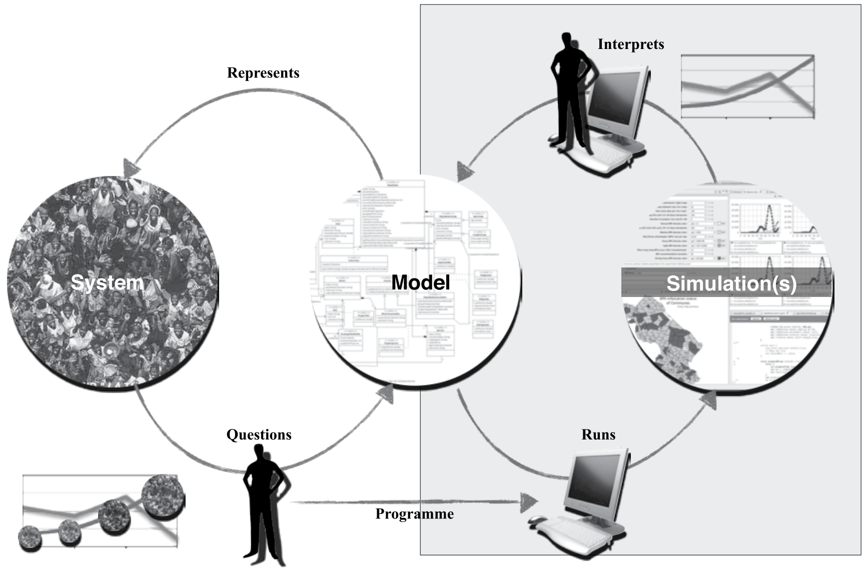
Sources: Authors' construction.

In an artificial manner, I distinguish static models, which are the representations at a given moment of a system, from dynamic models.

Static models are not supposed to refer to any kind of dynamic of the system: they are used to expose and simplify what the system is, to communicate it and aid reflection. A model presenting the institutions of the French Fifth Republic is a static model of how the institution functions. The question asked is one of representation.

Conversely, dynamic models concern the dynamic of the system and are linked to its evolution. This may be a temporal evolution – the most common case – or it might well be a structural evolution. We may be interested in variations of the system that are not necessarily variations in time. There are, for example, predictive models that are supposed to report back: the model predicts and anticipates in time how the system will evolve.

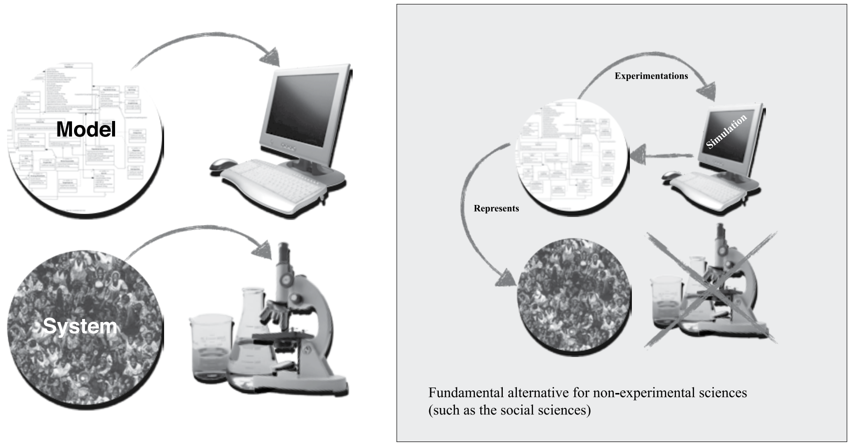
Diagram 9 Computer Model and Simulation



Sources: Authors' construction.

The computer models are very closely linked to dynamic models. A dynamic model in computer science is called a simulation. For example, when we cause variations in a model, we run that model. We have a system, with on the one side an agent, or a group of human agents, who ask a specific question about a reference system that is demarcated in reality. This may be a social system. The players are then going to build an abstract model and at the same time programme it. This abstract construction is made to become something executable within the simulation, which unfolds in time and provides information in time.

Diagram 10 Computational Experimentations



Sources: Authors' construction.

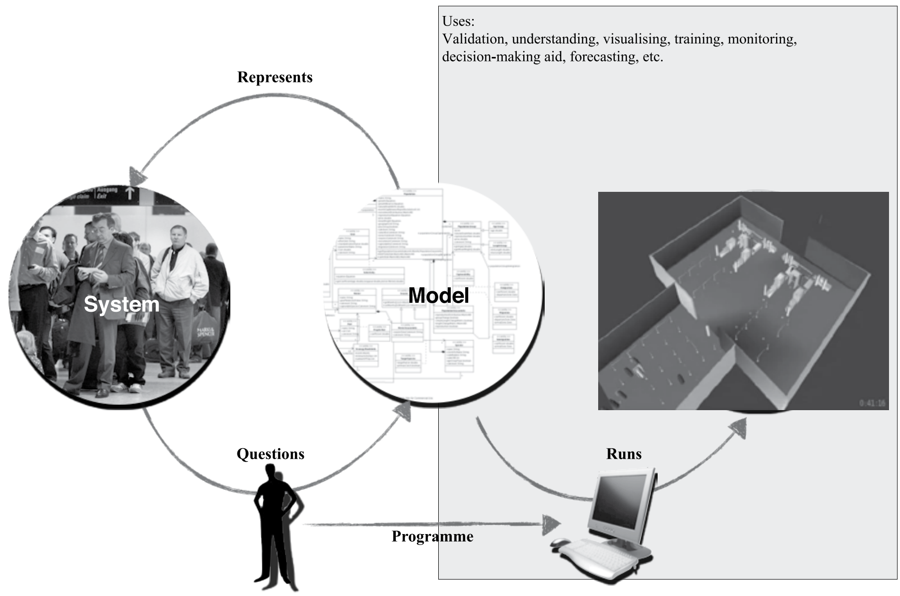
In the same way that we can write models on a piece of paper using different languages, we can write computer models by using different languages, representations and abstractions.

In what way are simulations interesting?

If you observe a simulation compared to a model, you will see that the definition is similar to that of an experiment in relation to a real system. A simulation is the perturbation of a model in order to provide answers to questions. In the same way, in an experiment in experimental sciences (chemistry, biology and others), we upset a model in order to push it to its limits and understand its way of functioning. Simulation allows this reproduction for its models. We can modify them, perturb them in a controlled manner, have particular variables changed, explore parameter spaces, etc.

Nowadays, we can remark that there are some experimental domains that can no longer be the object of experimentations such as nuclear physics, for example. Thus, the only solution is simulation, with all that that implies in terms of problems of representations and validity. Thanks to progress in computer science and its powers of calculation, new domains are becoming accessible to experimental options. It is the case for a certain number of scientific domains belonging to the social sciences. We can deal with these domains by using an experimental approach. We can now build models that are complex enough to be simulated, in order to reproduce relatively complex dynamics on computer and explore a certain number of possible trajectories, particularly by modifying the system's inputs.

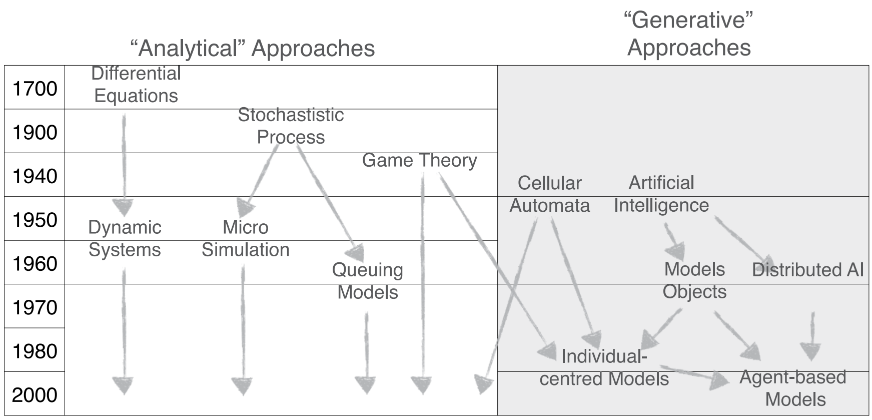
Diagram 11 Dynamic Models, Simulations: The Best Approach?



Sources: Gilbert, N. and K. Troitzsch (2005).

The uses of simulation can be scientific. We can for example verify a certain number of properties regarding people queuing in a place, but this may also have a purely commercial use – how to implement the "right" sort of queue to avoid crowding and lengthy queues. The current uses of simulation, all applications considered, concern the validation of models; it is a real case of experimentation. We build a model of a reality, and then we validate it by observing all its possible futures. The understanding of a model and its visualisation are important points. Models can also be used for training, monitoring, decision-making aid, forecasting, etc. Two domains of application carry a heavy financial weight in the world: the military domain, which is the biggest consumer of simulation, and that of video games – the majority of progress in simulation over the last twenty years stems from the world of video games and its needs.

Diagram 12 Structure of an Agent-based Model



Sources: Authors' construction.

Within dynamic models we can distinguish two big families: one that is related to so-called analytical approaches and a more recent one that is very closely linked to progress in computer science and related to the so-called generative approach.

What differences can we remark?

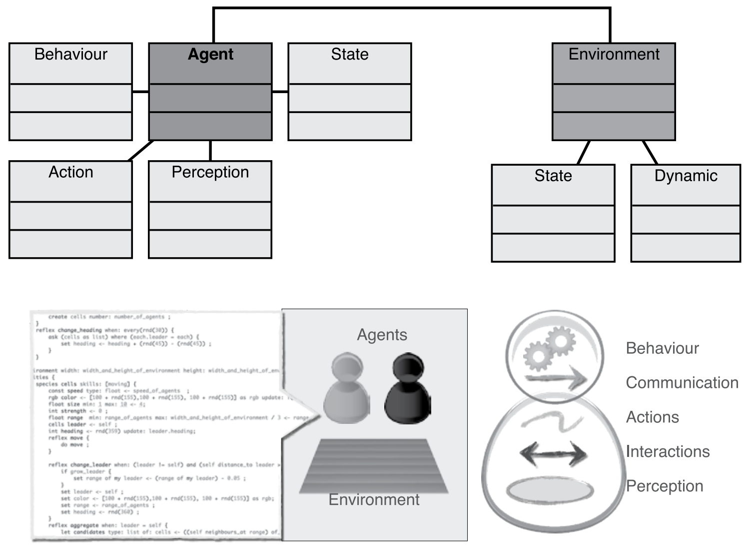
The analytical approaches are used to characterise the states of balance of a system, to describe it in such a way as to perturb it in a controlled manner.

Conversely, the generative methods allow us to generate these equilibriums and understand the conditions of their emergence.

From the components and constituent parts of a system, we are going to make them act and interact in order to attempt to find the equilibriums in a way which will help us to understand how they are formed – such as, for example, a social group, an equilibrium in a negotiation. If you are interested in the dynamics of a population in an environment, analytical approaches will represent these states of equilibrium by equations so as to obtain a simplified, macro and global image which ignores the constituent parts of the system. As for generative approaches, they will represent each element of the population and the environment in order to attempt to reconstruct states of equilibrium by using hypotheses about the individuals. These two approaches are not necessarily opposed and may cohabit within the same system.

The generative approaches date back to 1945, with the first computers and the first attempts at simulation that were used for the atomic bomb. The first approaches to simulation corresponded to a certain number of domains and techniques: cellular automata and artificial intelligence.

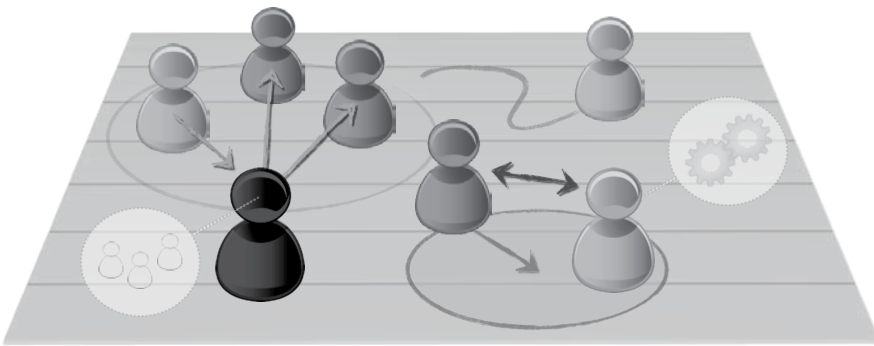
Diagram 13 Agent-based Models



Sources: Authors' construction.

Agent-based models constitute a way of representing a system. In order to represent this system, we are going to use a small number of concepts that are both rich and polysemic when taken individually into account. These models group together two important concepts: the agents and the environment. An agent is a computer programme which can be executed and which includes behaviour, communication (the sending of information to other agents of the system), and actions (modification of other agents, of the environment or oneself), interactions and perception (ability to perceive other agents' vicinities). We are here within an anthro-centred approach from a vocabulary point of view. We construct computer programmes to which we give attributes that are almost human and living. In computer science, we have systems that allow us to say *"I want to create an agent, its behaviour, its communications, etc., and I am going to programme it in such a way"*. All of the programmes we have built in this way are then placed in situation in the environment, which is also a computer programme; this can be something distributed on the web, a grid, a table, a matrix from the moment when we are in possession of characterisable states, when we can perceive phenomena and recuperate information.

Diagram 14 Agent-based Models



Sources: Authors' construction.

These agents are placed in situation and we have an experimental system. In an agent-based modelling approach, we give ourselves the means to create small virtual worlds. We create a virtual world over which we have complete power. The problem no longer lies in what we can and cannot put in, but in the way in which we are going to use it. How are we going to interpret, validate, and experiment with it? In terms of expressivity, we shall see during the workshops that it is possible to construct troubling things in terms of realism.

These micro-worlds have no imposed structure. We can use data stemming from very different sources, quantitative or qualitative. Programming an agent can also be "literary" even if the vocabulary differs from that of a book. A programme is not only constituted of algorithms, it can also be in the form of a description of behaviours.

I looked for a very simple model about water, but I didn't find one. I preferred to opt for a segregation model. We take a very demarcated and simplified system and we interest ourselves in questions of social segregation. Segregation designates any evolving phenomenon or any state of separation of social groups on an infra-urban, urban, regional or national scale, eventually confirmed or favoured by law, socially legitimised, and which leads to the forming of segregated areas, heterogeneous territories and frontier spaces. The challenge that we often encounter in urban environments is to analyse the mechanisms at work in the forming of segregation. How and why does it appear when it is not imposed by law and does not result from any personal preference (according to survey results)?

Box 6 Schelling Model

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  O # O # O #
```

Figure 3

No one can move, except to a corner, because there are no other vacant cells; but no one wants to move. We now mix them up a little, and in the process empty some cells to make movement feasible.

There are 60 coins on the board. We remove 20, using a table of random digits; we then pick 5 empty squares at random and replace a dime or a penny with a 50-50 chance. The result is a board with 64 cells, 45 occupied and 19 blank. Forty individuals are just where they were before we removed 20 neighbors and added 5 new ones. The left side of Figure 4 shows one such result, generated by exactly this process. The #'s are dimes and the *O*'s are pennies; alternatively, the #'s speak French and the *O*'s speak English, the #'s are black and the *O*'s are white, the #'s are boys and the *O*'s are girls, or whatever you please.

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— # — # O # — O     — — — # — # — —
# # # O — O # O     — — — — — — — —
— # O — — # O #     — — — — — — — —
— O # O # O # O     — — # — # — # —
O O O # O O O —     — — — — — — — —
# — # # # — — O     # — — — — — — —
— # O # O # O —     — — O — O — O —
— O — O — — # —     — — — — — — — —
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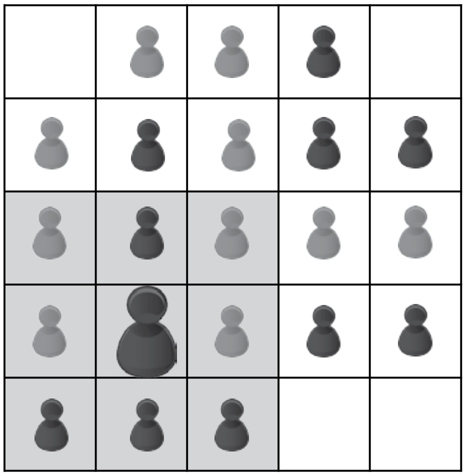
Sources: Schelling, T.C. (1969).

These questions are at the base of the Schelling model that was later used to construct more complex models. In 1969, Tom Schelling in his article Models of Segregation asked these two questions in the context of a black/white report in American suburbs. How was it that when individuals replied to questions in surveys stating that they had *"no problem living with 70% blacks although I am white, or with 70% whites although I am black"*, reality showed a case of almost 100% segregation.

What forces and dynamics are at work that can explain this situation? How can we reproduce this situation in order to eventually anticipate it in the framework of urban planning for example?

Diagram 15 Model Description



Sources: Authors' construction.

Tom Schelling had an extraordinary intuition: he took as his starting point the simplest of systems. Maximum simplification means avoiding taking into consideration the particularities of the city and the profiles and complex preferences of the individuals.

Agents of both colours live on a chequerboard. Independently of any other activity and of what they can do elsewhere, they are going to be happy or unhappy in this habitat according to an individual preference expressed by the number of neighbours of the same colour, or a different colour, that they wish to have around them. *A priori* everybody has the same preferences. For example, *"if the percentage of neighbours of the same colour is inferior to 30%, I will be rather unhappy; if this percentage is higher than 30%, whatever the percentage, I will be rather happy".* The model is childlike in its simplicity! This approach is prototypical of an agent-based one. You can see that the notion of population does not appear. Individuals are capable, locally in a particular environment, to spot particularities, pick up information, and they are to make a decision depending on this perception. The only thing global is constituted by environmental constraints. As far as behaviour is concerned, to avoid any bias in the model, the movement of agents when unhappy is totally random.

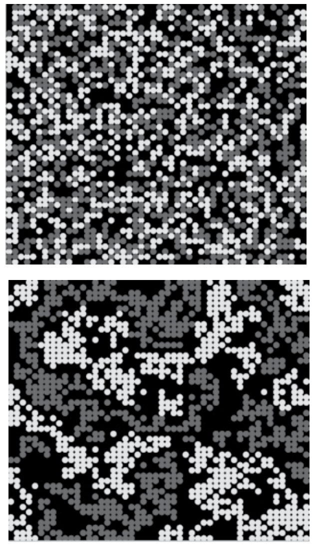
They randomly choose a square and go there. We have time advance; at each step in time, the agents will decide whether to move or not.

Diagram 16 Results of the Model

Initial situation
Grid : 50 x 50
1 200 agents
Individual preference: 35%

Segregation rate (∑similar neighbours/∑ neighbours) : 49.9%

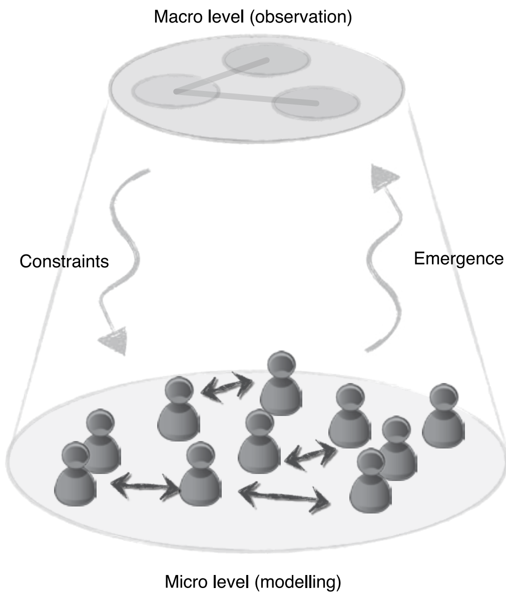
Final situation (equilibrium)
Segregation rate: 94%



Sources: Authors' construction.

All the simulations made on this model show that with rather weak individual preferences – such as accepting to live with only 35% of people of the same colour – we arrive at segregation rates of near to 100%. This is subsequently explained by almost physical phenomena. However we interpret the results, it is interesting to see that we have an example of what we seek to obtain: the emergence of properties and equilibriums, at a population or given group level, which are not inscribed in the agents which compose the population or the group. This state of equilibrium is not programmed, it is not given, and it is not an input of the model. It is simply the case that after a certain time and a certain number of iterations, the model reaches equilibrium. Experimentation and simulation are indispensable steps in order to be able to obtain such properties.

Diagram 17 Generative Aspect of Agent–based Models



Sources: Authors' construction.

These simple models take into account two scales: the micro scale (individual) and the macro (population) one. Of course, it is possible to take a lot more scales into account, for example meso scales in which other agents will be constituted, which will themselves have interactions. Agent-based approaches, or individual-centred approaches in biology, are based on a micro-level modelling and the simulation and interpretation operate on a macro level – whereas most analytical models are situated on the same scale.

The other advantage of this approach is that an agent can take on multiple forms: individuals, households, social groups, etc. In other domains, the avian flu virus, towns and even ducks can be agents. The level of analysis depends upon the question posed; it is neither static nor fixed.

Another advantage is the representation of this environment. Explicitly, we are going to require the agents to be situated, even in cases when this may appear a little artificial. The notion of environment is not really well specified. Scientific research related to agent-based models shows great diversity. We are going to use databases – geographic ones for example – to represent the environment of realist models. But you can also represent grids, environments without any particular metric or topology. An environment can also be a social graph, a social network in which agents are situated, which gives them a perception of their neighbourhood.

The Schelling model that we saw on a grid can be made spatially clear so as to take into account particular topologies. We have here two examples with data taken from Google

Maps™. The agents are going to use the colours of the map in order to know where to place themselves (roads, buildings, etc.). It is an example of an environment in which the agents use information.

Maps 9 and 10 Spatially Explicit Segregation, Example of Hà Nội

Sources: Authors' construction; Crooks, A. T. (2010).

Here, we go a little further by directly using a GIS. We have, in this case, a district of Hà Nội in which we make the agents act. Evidently the notions of neighbourhoods are no longer the same, we must redefine them, but the agents' behaviour does not change any more than their capacity to make decisions. What changes is their perception and their way of moving.

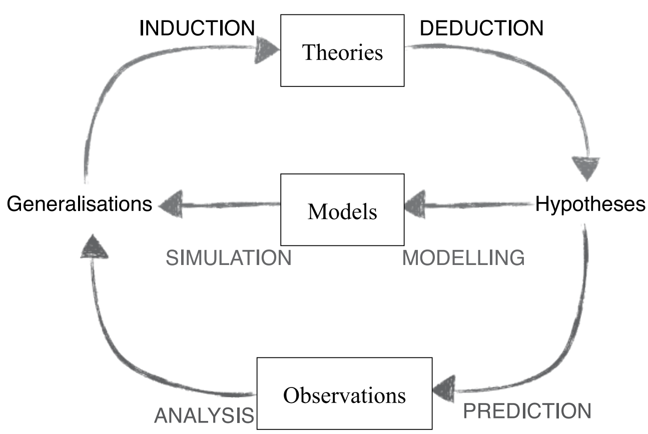
How can we describe an agent's behaviour?

The principal metaphor of agent-based models came at the end of the 1980s from social sciences, and those that we are going to principally use to programme agents come from either ethology – science of animal behaviour – or psychology, which has had a sometimes incestuous relationship with artificial intelligence over the last thirty years. Here, we have metaphor transfers. We can use neurone networks, rule-based systems. As computer scientists, we are used to this diversity of representation. We juggle between representations and metaphors. You can see here that, at the end of the day, the world I present with an agent-based model is a world that is a little more complex than the world of maths-based analytical systems in which the vocabulary is relatively finite and well defined.

You are going to invent a model of behaviour and a way of representing these behaviours; what is most important is that it makes sense for you and the others in the interpretation.

Once the virtual world has been constructed, a new world opens up in the domain of the interaction between the user of the model and the model. From here, we have access to things that belong to the domain of visualisation: we can play with the model, modify its parameters at any moment, have users intervene within it, and create learning dynamics, for example. The user is going to learn things from the model that will constitute a good part of the informal validation. Laboratories are created which allow us to scrutinise and dynamically modify these worlds.

Diagram 18 Social Sciences, Simulation, Agents



Sources: Authors' construction.

In social sciences, simulation offers the possibility of implementing controlled computational experimentations. Its objective is not to construct theories, but to generate, in a controlled manner, data that can then be analysed, which has the specificity of coming from experimentations and not from observations of the system.

In this system, agent-based models, because of their flexibility and versatility, already occupy an important place, which will no doubt become progressively more important.

This zoology of artificial experimentation on the models is a new way of carrying out research, particularly because it creates data that does not really belong to a system but to models of a system, then we will build theories from this data. Yesterday we spoke about climate change and scenarios that are often built on this type of model and data that do not stem from reality, but from projection and models of reality.

Agent-based models present multiple advantages for social sciences:

- Possibility of representing qualitative and quantitative data;
- No constraint on the type of formalisation;
- No constraint on the level of representation;
- Possibility of an experimental approach on micro-worlds;
- Possibility of participative approach (immersive micro-worlds);
- Possibility of representing heterogeneous players;
- Possibility of basing oneself on spatial data or real statistics (for calibration and experimental research).

When do we use agent-based models?

- When it is difficult to test hypotheses only from observations;
- When the players in a system are very heterogeneous;
- When it is possible to identify relationships or intermediary organisations that influence the dynamics of the system;
- When the level of analysis is not fixed and may fluctuate;
- When macro level changes must be the results and not the input of the model.

Benoit Gaudou

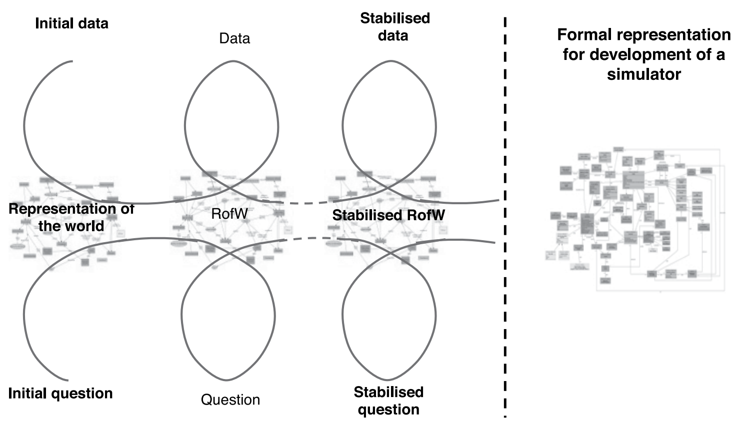
I am going to present the MAELIA project that is being carried out in Toulouse. This project began in 2009 and will finish in 2013. Consequently, the results are not yet definitive; we are still in a prospective phase.

The aim of the project is to develop an integrative modelling and agent-based platform to study the socio-environmental impacts of the norms (social and legal rules of the organisations) implicated in the management of renewable natural resources (particularly water). We are more precisely interested in the "Bassin Adour Garonne". One of the particularities of this zone is a lack of water, particularly in summer during the period of low water and of user conflicts – for example between irrigation for corn crops, swimming pools, or water for the city of Toulouse. The drop in the water level implies ecological problems and crises, particularly for farmers.

In the framework of low water management, there is a whole system of laws and norms implemented from the European to the local level. We are interested in the ecological, economic and social consequences of the implementation of these new policies. This involves three major initial issues:

- What are the economic, social and environmental impacts of the different alternatives of definition/management of the volumes of water to be used?
- What is the technical/social feasibility (acceptability) of the different alternatives?
- What is the robustness of the different options?

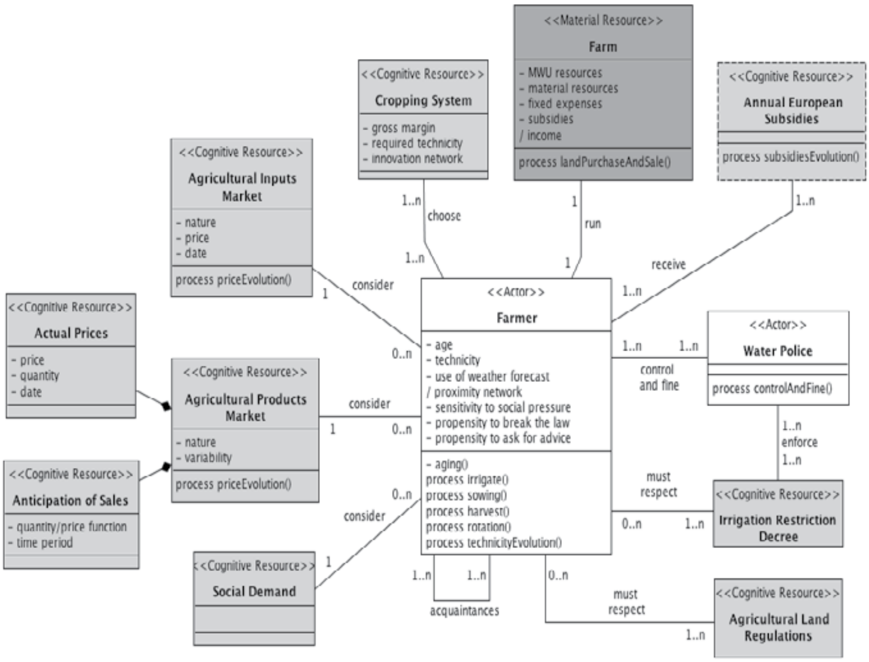
Diagram 19 MAELIA: An Interdisciplinary Modelling Project



RofW = Representation of the World.
Sources: Authors' construction; production of the MAELIA project (non-published).

The difficulty and interest of this project is to integrate – *versus* juxtapose – the knowledge of researchers from different subjects, particularly from social sciences, hydrology and agronomy. We had a certain amount of initial data around which we built and represented a "world" in order to implement it, run it and test several hypotheses. What I call "representation of the world" identifies a model of all the agents and their dynamics implicated in the system in which we are interested. At the launch of the project, sociologists, hydrologists, agronomists and computer modellers, etc. were involved in the project and the different discussions about it. The fact of establishing this representation allowed us to agree on the vocabulary. A certain number of iterations were necessary to arrive at a stabilised representation. It is important to note that these iterations represent a coevolution of the necessary knowledge and data, of the representation of the world and of the question to which it is hoped the model will provide answers.

Diagram 20 Principal Agents: The Farmers

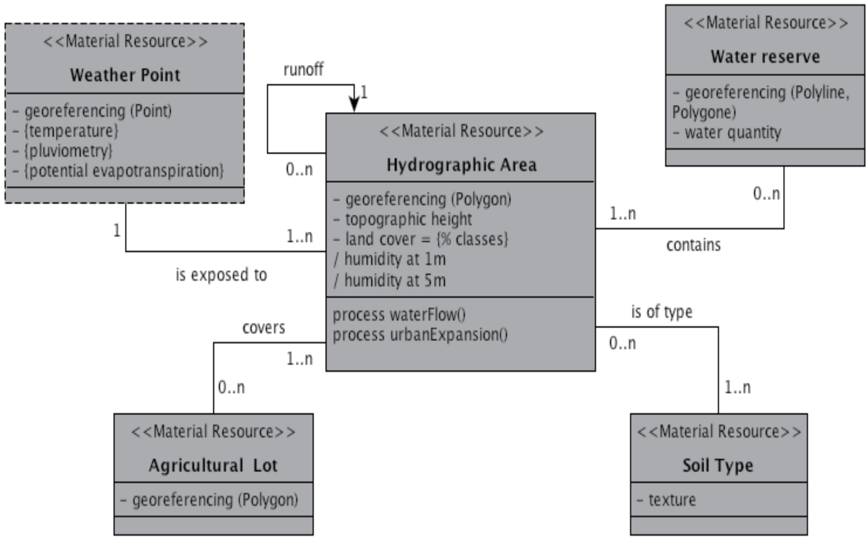


Sources: Authors' construction; production of the MAELIA project (non-published).

One of the principal players of the model is the "farmer" entity with a certain number of associated characteristics. The links between the farmer and the different related boxes represent the relationships between the farmer and other concepts that we wished to mobilise in the model (for example, the size of his farm or the agricultural product market).

The hydrological zone is a second example of an agent considered in our model. It is the principal entity of all the hydrological processes. The hydrological zone is situated at a superior level (in terms of spatial scale) to all that is agricultural. The type of soil is taken into account because, according to its nature, water evidently does not infiltrate it and flow in the same way. These two diagrams are a part of the static view of the model.

Diagram 21 Principal Agents: Hydrological Zones



Sources: Authors' construction; production of the MAELIA project (non-published).

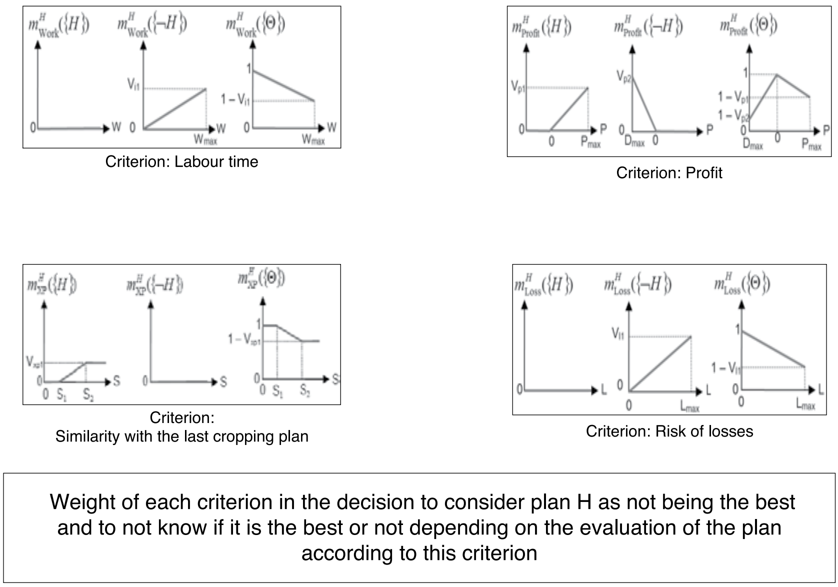
We have identified twenty or so dynamics that we wish to implement in our model. The five principal ones are:

- The flow of the water (hydrological zones);
- Plant growth (plots);
- Choice of crop rotation (farmers);
- Execution of crop rotation plans (sowing, fertilisation, irrigation, harvest, resulting from the farmers' choices);
- Formal framework (irrigation restriction decree issued by the prefect).

We worked with the *Institut National de Recherche Agronomique* (INRA), which had undertaken studies about farmers' strategies concerning crop rotation plans. Four principal criteria stood out: hours of labour, profit, similarity with the last crop rotation plan and loss risk.

Once these criteria had been identified, we became interested in the influence they have on the farmer's decision: for example, by considering the other identical criteria in two plans, the plan that minimises hours of labour will be preferred to the one requiring longer hours of labour. The chosen formalism to describe the decision-making process is that of the multi-criteria decision using Dempster-Shafer belief functions: for each of the criteria, an evaluation function relating to this criterion and three functions referred to as "belief functions" are associated. The first belief function describes the weight that this criterion has in the decision to consider the considered plan as being the best, the second belief function the weight to consider it as not being the best, and the last one indicates the farmer's inability to determine whether it is the best or not.

Diagram 22 Example of the Process: Choice of Crop Rotation



Sources: Taillandier et al. *(2012).*

We have presented the static model that describes the different objects and their relationships and the different processes linked to the dynamic of the system. From these two elements we can implement a computer model. The following work stage considers the execution of this model and the observation of its results.

Most of the processes involved in this model are going to necessitate a certain number of data in order to be executed and produce interesting results. A big task, and one of the project's major products, has thus been the constitution of a database (and particularly of a GIS) adapted to our model. We have, for example, cross referenced data coming from diverse GIS, as well as beneficiary tables, in order to produce an aggregated GIS containing rivers and reservoirs, irrigated zones and the watering points associated with each zone.

We are now ready to execute our model (launch simulations) and evaluate a certain number of scenarios considering the indicators. The two scenarios that for the moment have been identified are linked to the two following factors of change: the definition of the volumes of water available and climate change (in terms of rainfall and temperature).

There are three types of indicator considered:

- Bio-physical: water flow at the control points of the Low-Water Target Flow *(Débit Objectif d'Etiage, DOE)*, pollution, production of irrigated crops;
- Economic: production of agricultural holdings; cost of the implementation/

functioning of the alternative management method;
- Social: frequency, date and gravity of crisis situations, acceptability (respect or non-respect of norms).

Thank you very much.

Selected Bibliography

Principal sites (articles free to access):

JASSS: Journal of Artificial Societies and Social Simulation: http://jasss.soc.surrey.ac.uk/

ACE: Agent-based Computational Economics: http://www.econ.iastate.edu/tesfatsi/ace.htm

GisAgents: GIS and Agent-Based Modelling: http://www.gisagents.blogspot.com/

OpenABM: Open Agent-Based Modeling Consortium: http://www.openabm.org/

Three free agent-based modelling and simulation platforms:

NetLogo: http://ccl.northwestern.edu/netlogo/

Repast Simphony: http://repast.sourceforge.net/

GAMA: http://gama-platform.googlecode.com.

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Exchanges…

Claude de Miras

I didn't understand the assertion according to which the individual scale did not interfere in the final situation. I understood your presentation as being the contrary demonstration of the impact of implicit individual choices that, once collectively aggregated, produce the result you have described. You insisted on the scission in the passage between the individual and the global, as being a rupture, whereas the demonstration is founded, on the contrary, on the continuity of these two scales.

Catherine Baron

Which social sciences and which approaches are you evoking when you speak about the implantation of social science metaphors in computer science? Would a change in your social sciences assumption have an impact, and if so, what?

How do you integrate the new work and research in economics into the rationality of the agents? Finally, in relation to MAELIA, how do you integrate the conflicts that often modify existing rules and result in the emergence of new ones? How does this modelling allow us to account for these aspects in a dynamic fashion?

Alexis Drogoul

In the results obtained at simulation level, there was something which was not intuitive: the individuals with a preference rate of only 35% for neighbours of the same colour finished by creating a system which was 100% segregated. The relationship between individual preference and the result obtained was not intuitive.

Claude de Miras

It is an assumption to affirm that it is not intuitive. Is there not an implicit understanding that means that in societal practice, we know that if we have one neighbour in three of such a colour, we are going to have a phenomenon, a perception and a representation of an exceeded limit? There is perhaps a societal intuition that determines this type of evolution. What bothers me is the affirmation of the assumption, that this is not intuitive. This needs demonstrating. Consequently, this raises the question of hypotheses, which has not been addressed. The hypotheses in the choices that allow us to go from the system to the model, determine what the model will produce; however no allusion has been made to this.

Alexis Drogoul

The construction of a model always necessitates hypotheses. They are everywhere, even if they are not necessarily explicit. I believe that in computational approaches we tend to spell them out better, and they are all the more necessary in computer science as they are part of operational constraints.

Regarding the social sciences metaphor, in the 1980s there was a very big influence from the individualist, actionist approaches, from the sociology of organisations. A certain number of representations of economic systems were perfectly attuned to the vision of the neo-liberal wave of the 1970s and 80s. We nevertheless have to qualify this, as the vision computer scientists have of social sciences is extremely blurred. Groups of researchers have built concepts that we later use by questioning and "twisting" them.

Let us take another example from computer science. The networks of neurones are particular representations that allow a computer system to learn from examples. This is called a network of neurones, but has got nothing to do with the biological metaphor of the original models that were themselves a simplification of reality. The metaphor allows us to construct the concept or the meta-concept, that is to say the element that will allow us to construct the concept of the model. We can then represent any theory of the social, since the scale is not fixed and we are interested in emergence phenomena, but not exclusively: in Benoit Gaudou's example, the institutional system in all its richness, and with a certain number of norms, is imposed on players in an absolutely non-emergent manner. Expressivity is not limited by the initial use of the metaphor.

How can we integrate the envisaged rationality in economy? Implicitly, the initial players belonged as much to artificial intelligence as they did to economy. A large part of the theory, concerning the rationality of agents in economy, stems from artificial intelligence. Then we moved away from this because we cannot assume the rationality of players, in the same way as we cannot assume the homogeneity of their representations. Rationality is not necessarily an assumption or an original hypothesis. If we begin, for example, to build systems that contain qualitative data of individual narratives about the way people perceive the world, this may not be rational. We can perfectly imagine a player who makes random decisions. The models that we are building are not models that we must believe. They are models that are used as a support for discussion or negotiation between players. Very few predictive models exist.

Benoit Gaudou

Let us return to conflicts. Our model only proposes a prefect who issues a decree forbidding irrigation when water levels drop beneath a certain threshold. All the prior negotiation processes between the different players about the quantity of water to be used are not modelled. We would have to be able to determine a process that generates decisions. The catchment area council is made up of about two hundred people who have to get together and discuss things, which necessitates a certain knowledge that we have not yet modelled.

Trainee

Is the model a decision-making aid that helps farmers choose the most economically viable crop?

Benoit Gaudou

For this model we need geographical data to know the location of the holdings, which are those that use irrigation and which don't, and the type of crop. We also have data about crops that have been grown on a plot over the last ten years. We implement our farmer agents and calibrate over this ten-year period. We try to find coherent results by using the preceding results. Next, after this calibration phase, we consider that we are going to let the model evolve. This model in particular will not predict what it is necessary to plant or harvest on the fields. It will, however, indicate what will happen if water supplies dwindle.

Jean-Pascal Torréton

Just a remark that goes in the sense of what Alexis is saying about the limits of simulations and their capacity to reproduce complex phenomena. In the domain of experimental sciences, I see simulations as the representation of an experimental system used to test hypotheses. In biology, in oceanography or in science of the environment, we are led to carry out experimentations that are extremely simplified and criticised for this: for example, when we wish to evaluate the influence of climate change on the way oceans function. Therefore, I cannot see any fundamental difference with the definition of an experimental system by simulation.

Catherine Baron

However, it seems to me that when we are studying human societies and the economic stakes linked to them, the questions we ask are of a different order.

Alexis Drogoul

Regarding the difference between a simulation in marine biology and a simulation in social sciences, a macro model that represents a population is not only interested in individuals. We ignore any heterogeneity of the population, any individual choice or decision. On the contrary, I see all the approaches I have presented here as attempts to bring to the fore the dignity of all points of view. Models simplify and reduce, but is that not the limit of all models?